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POSSIBLE RAINFALL REDUCTION THROUGH REDUCED SURFACE TEMPERATURES DUE TO OVERGRAZING

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ABSTRACT

In arid regions the moisture-limited natural vegetation grows in clumps, covering only a fraction of the terrain. Dark plant debris lie on the surface lowering the albedo of the vegetated areas, both in the visible and the reflective infrared. In contrast, in overgrazed areas only few plants survive, soil is unstable and plant debris are covered by dust, resulting, in a very high area albedo contributed mainly by the bare soil. Surface temperatures in such denuded areas are lower when sun illuminated. Surface temperature reduction is postulated to decrease air convection, reducing cloudiness and rainfall probability during weak meteorological disturbances. By reducing land-sea daytime temperature differences, the surface temperature reduction decreases daytime circulation of thermally driven local winds. The described desertification mechanism, even when limited to arid regions, high albedo soils, weak meteorological distrubances, can be an effective rainfall reducing process in many areas including most of the Mediterranean lands.

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INTRODUCTION

Local modification of rainfall by anthropogenic influences has been discussed by Changnon et al. (1971). They reported that a notable anomaly, in which the summer rainfall is locally enhanced by 15%, appears 15 km southeast of St. Louis, essentially to the lee of this city, considering the prevailing winds. They attribute the anomaly to the heat island effect of St. Louis.

The phenomena has been studied in other locations. Thus, for instance Parry (1956) cites an occurrence for Reading, England, where a nonfrontal storm yielded 34.5 mm over the city and only 2.5 mm in the rural area. The conditions as observed by Parry were: slow moving, conditionally unstable air to 2 km, moisture content high to 3 km and instability present from 4.5 to 8 km. Parry suggests that even 1° C heat island might become a rainfall triggering force under such conditions.

The subject of rainfall induced by the urban heat islands is subject to considerable controversy, centered on the statistics involved in the reports (Landsberg, 1974). However, as Landsberg points out, there is a very plausible physical model for inducing precipitation by a heat island, in which the increased surface temperatures of a city stimulate ascending air currents, cloud formation and precipitation.

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An opposite anthropogenic effect, of rainfall reduction, can be postulated: if overgrazing and cultivation result in cooler surface temperatures in an area denuded from vegetation, as compared with a vegetated area, under sunlit conditions. Such an effect has been called a "thermal depression" (Otterman, 1974), but a simpler term surface temperature reduction is used here. The concept was conceived (Otterman and Waisel, 1974) as a result of:

(i) inspection of the ERTS imagery of the Negev-Sinai boundary, showing the denuded area as sharply brighter in all the bands of the ERTS scanner, surprisingly even in the infrared,

(ii) familiarity with the Negev vegetation which is typically quite dry and grows in sparse clumps, which cover only a fraction of the surface. For this type of canopy the thermal inertia and evap transpiration effects were expected to be of limited significance.

The surface temperature reduction in the Sinai on one hand, or higher surface temperature in the Western Negev on the other, has been in a fragmentary way confirmed by ground, aircraft and satellite radiation temperature measurements. The observations and studies of the reflectivities/albedos, of the surface temperatures and of the possible direct meteorological/climatological effects are presented in this paper.

THE INFRARED REFLECTIVITY PARADOX OF THE WESTERN NEGEV

The fact that the typical vegetation is highly reflective in the infrared, is well recognized. This actually was the reason for developing the infrared camouflage detection film—in which vegetation appears bright, green camouflage paint—dark. "The very abrupt increase in reflectance near 0.7μ and the fairly abrupt decrease near 1.5μ are present for all mature, healthy green leaves" (Gates, 1970). Typically, reflectance of plants lies in 35-80% range for the infrared wavelength interval from 0.7 to 1.1 micrometers. It is typically only 5-10% in the red 0.6-0.7 micrometers interval, where a chlorophyll absorption band lies (see Gates, 1970, Figs. 5 and 7; also Myers, 1970, Figs. 1, 2, 3, 5, 6, 12, and 13). Where the plants cover only a fraction of the ground, increased infrared reflectance of surface is expected with an increase in the ground cover fraction, an increase of the plant projection, height and the leaf surface index of the vegetation. Accompanying this increased reflectance in the infrared is a decreased reflectance in red (Thomas et al., 1966; Vinogradov, 1969; Colwell, 1974).

It is fully expected that vegetation can be observed and mapped from satellites, based on the "signatures" of vegetation, i.e., spectral reflectance characteristics. Indeed, agricultural mapping is one of the key tasks of the Earth Resources Technology Satellite (ERTS) Program. Thus, space contrasts reflect well the ground characteristics, even though an allowance has to be made for the contrast attenuation by the atmosphere.

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The first satellite in the series, ERTS-1, launched in July 1973, provided high quality, high resolution (80 m) multispectral imagery of Israel for multidisciplinary studies under an Israeli program approved by NASA (Otterman et al., 1974a). Imagery on the first pass over the coastal area of Israel, on October 22, 1972, shows in a surprisingly sharp contrast the 1948/49 armistice line between Israel and Egypt, which geographically separates the Western Negev from the Sinai and Gaza Strip, Fig.1. The area of Western Negev, where grazing is limited by a fence, shows up dark in all the bands, compared to the bright Sinai and Gaza Strip (Otterman, 1973). Ground truth studies indicate that the grazing, cultivation in small sections, and picking up by the Bedouin of some plants for construction of their desert huts and for firewood, causes deterioration of the plant cover: the vegetation covers typically 25-35% of the surface in the Negev, (but up to 80% in small, isolated depressions) and pronouncedly less than 25% in the Sinai. The Sinai vegetation is locally so variable that an accurate estimate of plant cover fraction is even more difficult than for the Negev, but it could be estimated for the Northern part of Sinai as about 10% (Otterman and Waisel, 1974; Otterman et al., 1975a). In Figs. 2 and 3, ground views of the area are presented.

The observed low reflectivity in the infrared band, MSS-7 of the Western Negev--see Fig.1, was totally unexpected, and can be referred to as the Negev infrared reflectivity paradox.

The radiances from pairs of points (or rather small training areas), on both sides of the Sinai/Negev demarcation line were measured from the ERTS digital tapes using General Electric Image 100 Analyzer. The ratios of Sinai/Negev radiances for 3 pairs of points are presented in Table 1 for two days: Oct. 22, 1972 and Jan. 2, 1973. From the average signal counts in the training areas (pair #1, close to the Gaza Strip where the contrast is strongest), albedos were computed

Table 1

MSS Band		Sinai/Negev, 22 Oct 1972			Sinai/Negev, 2 Jan 1973		
#	μm	1	2	3	1	2	3
4	0.5~0.6	1.55	1.29	1.23	1.49	1.26	1.19
5	0.6~0.7	1.88	1.41	1.30	2.03	1.53	1.24
6	0.7~0.8	1.87	1.41	1.29	1.85	1.43	1.23
7	0.8~1.1	1.73	1.33	1.27	1.69	1.36	1.22

by R. S. Fraser, NASA, assuming a low turbidity atmosphere and 15 mm water vapor in October and 10 mm in January. The results are tabulated in Table 2. The water vapor assumptions were based on measurements in the Negev by J. Joseph (Joseph, 1975). The rainy season albedo show both in the Negev and the Sinai a small decrease in MSS-5 and a small increase in MSS-7, as compared to the fall albedo. These changes are consistent with an expected increase as a result of the winter rains in the natural vegetation in the Negev and both the natural and the cultivated vegetation in the Sinai.

Table 2

	Sinai		Negev		Contrast Ratio	
	22 Oct 1972 Zenith 61.48	2 Jan 1973 Zenith 48.85	22 Oct 1972 Zenith 61.48	2 Jan 1973 Zenith 48.85	22 Oct 1972	2 Jan 1973
MSS-4	0.32	0.28	0.18	0.16	1.78	1.75
MSS-5	0.42	0.37	0.21	0.16	2.00	2.31
MSS-6	0.395	0.39	0.21	0.21	1.89	1.86
MSS-7	0.514	0.544	0.297	0.321	1.73	1.69

It can be seen from Table 2 that the scene contrast ratio of albedo, i.e., contrast of terrain albedo evaluated for ground level, averaged for both visible and infrared, is about 2.0. The terrain albedo of Sinai averages to about 0.36 for the visible and about 0.52 for the infrared. The computed infrared albedo depends critically on the levels of atmospheric water vapor assumed in the computation of the atmospheric effects. In an approximate calculation of the Sinai albedo, for all the wavelengths insolation, under moderately high sun elevation angles, an assumption is made that the infrared radiation at the ground is 2/3 of the total insolation (see Lamb, 1972, Fig. 2.10, p. 41, after Allisov et al.). We obtain for the Sinai an albedo $(1/3) \cdot 0.36 + (2/3) \cdot 0.52 = 0.47$. Assuming that the infrared radiation at the ground is only 1/2 of the total insolation would still result in an effective albedo of $(1/2) \cdot 0.36 + (2/3) \cdot 0.52 = 0.44$.

These high values in the infrared of the Sinai albedo exceeding 50% calculated by R. S. Fraser are surprising, but credible in view of laboratory measurements of reflectivity performed by W. A. Hovis. He found out in this range 0.8 to 1.1 micrometers reflectivities of :55% for Daytona Beach Sand 0.105 to 0.250 mm; 55% for gray clay, Bad Water, Death Valley, California; 58% for Red Sandstone, ground, less than 0.038 mm; 62% for Silica Sand less than 0.105 mm; 66% for Silica Sand, .105 to .250 mm and 63% for Silica Sand 0.25 to 0.5 mm.

These high values, higher than 50%, compare with 42% for Altantic City, N. J., beach sand; 45% for Daytona Beach Sand, 0.250 to 0.5 mm; 43% for Gypsum Sand, White Sands, New Mexico; 38% for Mojave Desert soil (Hovis, 1966; Hovis, 1975). The computed albedo of 0.47 as an effective average for all wavelengths at the ground level, is much higher than the results of Kondratyev et al (1974).

The paradoxical characteristics can be summarized as three separate points:

a) The vegetated area of the Negev is relatively dark in the red-infrared (0.7-0.8 micrometers) bands, where vegetation typically reflects strongly.

b) The Sinai/Negev contrast in the band MSS-5, 0.6-0.7 micrometers (which includes a chorophyll absorption band and where vegetation appears dark) is always higher than in the bands 3 and 4, but higher by a wide margin, as may be expected for typical vegetation, only in two pairs of winter measurements.

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c) There is but little variability in the contrast, between the fall, i.e., the end of the summer dry season, and the rainy season.

This paradoxical behavior of the vegetated area requires an explanation, and this is offered in the next section, in terms of the debris that litter the soil surface in the interstices of the vegetation clumps. Assuming in a pro-forma calculation that there are no debris in the Sinai, and that the debris are totally black, neglecting any possible shadowing effect of the vegetation and the entire contribution of the vegetation to the dark appearance of the Negev and attributing it solely to the debris, we obtain a result (analyzing MSS-6 albedo in Table 2, which does not change seasonally) that the debris cover 45% of the surface.

This calculated 45% fraction is higher than estimates from ground observations. The calculation probably indicates that while the role of the debris is important, the vegetation itself also produces a darkening effect, or that additional processes might be at work. Yet, at the present, it should be stressed that all the processes described here apparently hinge more on the interstices of the vegetation clumps than the vegetation itself. The processes are thus constrained to arid regions, where the vegetation is soil moisture limited, and therefore grows in clumps with large interstices.

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THE THERMAL MOUNTAIN PARADOX OF THE WESTERN NEGEV

The expression "cool as a cucumber" attests well to our ingrained knowledge that typically vegetation is cooler than the bare surface. Anyone whose feet felt scorched walking on a hot sandy beach, never having such difficulties walking over a lawn, can attest to this. For a more technical statement, Gates (1970) can be quoted: "A radiometer scanning bare soil and vegetation-covered soil will detect a strong difference between the two at noon on a clear day. A dark, dry loam in full sunlight may have surface temperatures as high as 50°C when the air temperature at a height of 2 m is 30° C. A stand of vegetation nearby will have leaf temperatures near or below air temperature" (p. 247).

Thus, "hot vegetation" is a concept contrary to our experience. However, the examination of the ERTS-1 images which indicate unexpectedly low reflectivity in all the bands for the vegetated area—with a strong contrast to the neighboring Sinai, coupled with knowledge that the Negev vegetation is rather insignificant and cannot affect strongly the thermal balance through its evapotranspiration and thermal inertia, suggested that the expected temperature relations do not hold for the vegetated Negev. Here, the importance of the low reflectivity in the infrared as affecting the surface temperatures should be stressed, since at the Earth's surface the reflective infrared constitutes more than 50% of the solar radiation under zenith, i.e. one atmospheric airmass, solar illumination, and this fraction increases with reduced solar elevation (see Lamb, 1972, Fig. 2.10, p. 41, after Allisov et al.).

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Thus, a possibility was raised that the vegetated areas of the Negev might be warmer under sunlit conditions, than the neighboring Sinai. Since important environmental consequences might result, as disc... sed below, studies were initiated in the winter of 1972/73 to answer this question through: (a) request for NOAA-2 satellite thermal data, (b) thermal flux simulation program, (c) ecological surveys on field trips to the area, (d) and aircraft overflights to measure the surface radiation temperatures from the air, by a Barnes Precision Radiation Thermometer (PRT-5).

To date, only one instrumented aircraft flight took place, at 1400 hours on 29 August 1973, in which the aircraft criss-crossed back and forth the Sinai/ Negev boundary about 15 to 20 km inland from the Mediterranean. The PRT-5, which measures radiation in the 8 to 13 micrometer interval, showed that the surface radiation temperatures were about 45° C on the dark side and dropped abruptly when crossing the boundary to 40° C on the bright side.

The measured radiation temperatures of 45° and 40°, correspond to kinetic surface temperatures of 53.46° and 48.33° respectively, if thermal infrared emissivity of 0.9 is assumed both for the Negev and the Sinai, for 5.13° difference in kinetic surface temperatures. The thermal emissivities of these areas have not been measured, but it is likely that the dark side has an emissivity higher than the bright side, due to a larger fractional ground cover by the vegetation.

The emissivity of the bare soil can be taken as 0.9, probably as a satisfactory estimate. The vegetation emissivity approaches unity, both due to a higher emissivity of leaf surface and to the multiple reflections in the canopy, which produce a cavity effect of a nearly ideal black body emission. It is an open question to what extent this applies to the Negev and Sinai sparse vegetation. Assuming emissivity of .95 for the vegetative fraction of the ground cover and averaging linearly in emissivity in proportion to the ground cover, one obtains emissivity of .905 for Sinai, with a 10% ground cover, and .9175 for the Negev with a 35% ground cover. Under this assumption, the actually measured radiation temperatures would correspond to kinetic temperatures of $51.9°C$ for the Negev and $47.9°C$ for the Sinai, for $4°C$ temperature differential. Following the term introduced by Black and Tarmy (1963) we refer to the thermal mountain of the Negev.

More recently thermal radiation maps taken by satellites in the 11.5 micrometer band (discussed below) strongly corroborate the PRT-5 aircraft measurements. When satellite data were not readily available, a digital computer simulation has been programmed for the computation of the time-varying surface temperature of a planar surface under the influence of natural environmental heat transfer processes. The program provides solutions of the one dimensional heat flux equation, with time dependent boundary conditions at the surface, which depend on meteorological parameters. The simulation was tested by comparison with actual field measurements in Israel, which showed that the simulation can reproduce the actual measurements with a satisfactory accuracy (Rosenberg, 1974).

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The program provided simulation runs for the Sinai and the Western Negev, under various assumptions of albedo, and meteorological conditions. The results indicated that peak temperature differences between 3.5° to 6.2° can be regarded as representative for conditions believed to exist at the Sinai/Negev boundary. If it is assumed that the areas affected are elongated enough so that the air temperatures in the surface layer are significantly affected, and are warmer above the thermal mountain by 1/4 of the thermal mountain ground temperature difference, then ground temperature difference of 8°C to 12°C can typically build up (Otterman et al., 1974b). The peak temperature differences occur in the early afternoon; nighttime temperature differences are quite small, below accuracy of the program.

In an attempt to clarify this double manifestation, in reflectivity and temperature, of the Negev vegetation paradox, radiation temperature measurements were made with hand-held PRT-5, aimed at identifying the temperatures of the components of the terrain. The measurements were made on June 22, 1974, at noon, in the Negev, very close to the Sinai boundary, about 25 km from the Mediterranean. Representative measurements (all from an area of 10 m X 10 m) can be reported roughly as follows:

Soil covered with debris — 60°

The same soil, no debris (close to a road) — 50°

The greenest of the grey-green bushes, some soil background — 40°

Bare soil, with no debris, can be regarded as a typical surface for the Sinai. As for the Negev, soil with the debris and some grey-green vegetation is typical. It appears from these data, that it is the dark debris lying on the surface that contribute to the Negev radiation temperatures being higher, more than off-setting the contribution of at least some cool vegetation (Otterman et al., 1975a).

The debris thus are important to the temperature average for an area, and in view of the low reflectivity of the vegetated area in the reflective infrared, MSS-7, and little variability of Sinai/Negev contrast with seasons, are apparently contributing materially to the dark appearance of the Negev. Why are the debris so much in evidence in the Negev and not in the Sinai?

The answer lies in more abundant vegetation to produce the debris, and also in the stabilizing effect that the vegetation has. The plants reduce the wind erodibility and the dust that would cover the debris. The ground surface conditions affect pronouncedly the process of the wind erosion (Chepil and Woodruff, 1963). On the other hand, the trampling by the grazing herds in an overgrazed area would tend to bury the debris, both by pushing the debris into the soil and by raising dust.* These processes are thought more important for the area reflectivity and temperatures than the direct characteristics of the vegetation.

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*Bryson and Baerreis (1967) suggested that desertification can be caused by dust raised from denuded areas, which dwells in the atmosphere over the desert affecting the radiative transfer.

The thermal radiation map of the region by the Scanning Radiometer of the NOAA-3 satellite is presented as Figure 4. The local time is approximately 9:30 a.m. The absolute radiation temperatures are indicated by only two-digit numbers, above 200°K or above 300°K. The Western Negev, as outlined in this figure, shows on the average radiation temperatures higher by 4.1°K than the outlined area of Northern Sinai. The cultivated and irrigated Nile Delta shows radiation temperatures by some 10°K lower than the deserts. The thermal mountain of the Western Negev can be also recognized in the thermal window data by Temperature Humidity Infrared Radiometer of Nimbus 5. Nighttime data do not show any detectable radiation temperature differences between Negev and Sinai.

REDUCED CONVECTION EFFECT IN DENUDED AREAS

Cold ocean surface has been postulated as causing reduced rainfall in two regions of the world. The stabilizing effect on the atmosphere of the cold Humbolt current that flows along the west coastline of South America has been considered by Wallen (1966) as a factor in causing the aridity in the region of the Atacama Desert. Similarly, along the west coast of South Africa (Namib Desert), where the Benguela current in the South Atlantic flows north, most of the coastal areas are semi-arid (Flint, 1959). A possibility of a similar effect due to reduced surface temperature because of overgrazing should be examined.

A flow over a mountain or a strong heating at the surface can cause locally an uplift of the airmass and convective cloud formation if the airmass contains appreciable moisture. Such an uplift as a result of heating by the ground can be quantitatively studied, by an analytical approach developed by Stern and Malkus (1953) for a two-dimensional problem of a steady state air flow over a heated island. They analyzed the vertical displacement of a streamline from its undisturbed level, upward of the island, as a function of the rate, at which heat is supplied to the air at a point in space, with undisturbed wind speed, stability and air layer temperature as parameters. Assuming that this heating can be described by eddy conduction, and that it is created and maintained by small-scale turbulence and (at low level flow below 500 m where most of the

heat is supplied) the contribution of convection motion to the heat transfer can be neglected, Stern and Malkus obtain for a convective flow over a heat island with a uniformly elevated temperature τ, the following equation, for $x \leqslant L$, where L is the length of the heat island

$$M_{(x)} = \frac{\tau}{sT_m} \left[1 - e^{-\frac{gsK}{U^3}x} \right] \tag{1}$$

where $M_{(x)}$ is the shape of the mountain above the heat island, x the distance along the wind direction from the windward edge of the island, s stability, T_m temperature and U wind speed, all in the undisturbed flow, K is eddy conductivity and g acceleration of gravity. The equation is valid for $x \leqslant L$, the length of island, and in the subsequent flow, descent occurs.

Equation (1) can be rewritten as

$$M_{(x)} = \frac{\tau}{sT_m} \left[1 - e^{-\frac{x}{x_0}} \right] \tag{2}$$

where $x_0 = U^3/gsK$ is the conventional decay distance of an exponential function, which can be also written as $x_0 = U^2/mgs$, where $m = K/U$, is the thickness of the mixed layer.

The expression τ/sT_m can be regarded as a potential peak of the thermal mountain, for sufficiently long heat islands, and $1 - e^{x/x_0}$, the mountain profile functional, which limits the height of the thermal mountain to less than the potential peak when L is not much longer than x_0.

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What we are interested in, is quantitative significance of these equations which were tested by Stern and Malkus against actual flow over Nantucket Island. First, we shall consider a typical potential peak $M_{(L \gg x_o)}$ of a thermal mountain: for $\tau = 5°\,C$, $T_m = 300°\,K$ and $s = 10^{-7}\,cm^{-1}$, one obtains

$$M_{(L \gg x_o)} = \frac{5}{300 \cdot 10^{-7}} = 1.67 \cdot 10^5\,cm = 1670\,m$$

Now consider the decay distance x_o. For wind speed $U = 5\,m/sec$ and thickness of mixed layer $m = 25\,meters$, we have $x_o = U^2/m s = 25 \cdot 10^4/25 \cdot 10^2 \cdot 10^3 \cdot 10^{-7} = 10^6\,cm = 10\,km$. For a heat island 10 km long, we have:

$$M_{(x = x_o)} = 1670 \left(1 - \frac{1}{e} \right) = 1670 \cdot 0.632 = 1063\,m$$

Based on this result, we can say that convection effects of surface differences of overgrazed vs. protected areas may be highly significant, even for small areas such as 10 km long. It should be pointed out that both $M_{(L \gg x_o)}$ (for a given τ) and x_o depend pronouncedly on meteorological parameters. Especially x_o, which is roughly proportional to the square of wind speed, can vary by more than two orders of magnitude, from ~ 1 km to ~ 100 km (Stern and Malkus, 1953). More detailed analysis how x_o affects the convection are warranted where one would plan animal exclosures as countermeasures to overgrazing. Here we should point out, that when overgrazing occurs over areas 30 km long or more—up to hundreds of kilometers, either nearly full or appreciable fraction of $M_{(L \gg x_o)}$ convection occurs. Examining the equation

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$$M_{(L \gg x_0)} = \frac{\tau}{sT_m} = \frac{\tau}{\Gamma - \alpha} \qquad (3)$$

where Γ is the dry-adiabatic lapse rate and α the undisturbed lapse rate upwind
of the heat island, one can notice that $\Gamma - \alpha$ is generally of the order of
$10°/km - 7°/km = 3°/km$, which would correspond to stability of $\sim 10^{-7}\,cm^{-1}$, as
in our calculation above. $\Gamma - \alpha$ can range from zero for the adiabatic lapse rate,
to $\Gamma - \alpha = 12°/km$ in an inversion. Thus, $M_{(L \gg x_0)} = 1670$ m as calculated for
$\tau = 5$ and $s = 10^{-7}\,cm^{-1}$, would shrink by a factor of 4 under an inversion condition.
But 400 m convective motion in a general inversion is certainly a strong effect.

It can be postulated that such convective motion can typically give rise to
cloudiness when flow of moisture-laden air is involved, as discussed earlier.
Conversely, a reduction of surface temperatures because of overgrazing, will
significantly reduce cloudiness.

It should be pointed out that over the oceans, Malkus (1957) observed high cor-
relation between trade cumulus cloud groups and regions of ocean temperature
elevated by fraction of a degree. Over land, observations of convection cumulus
forming on the warmer shore are quite common, but an interesting case from
ERTS imager y is shown as Fig. 5: the exact conformity of cloud formation to
the shore line, ever in small estuaries, is striking. In the vicinity of urban
area heat islands, where the temperature rises 1 to 2°C above the surrounding,

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localized increased cloudiness and summer rainfall have been reported (Changnon et al., 1971), as discussed in the Introduction.

A mid-morning image of the Sinai-Negev area from Gemini XI, shows a cumulus cloud group over the Western Negev, with a well defined boundary coinciding with the vegetation demarcation line. There are practically no clouds southwest of the demarcation line, over the area of the postulated reduced temperatures in the Sinai (Fig. 6).

REDUCED SEA-BREEZE EFFECT IN DENUDED COASTAL AREAS

The main mechanism of desertification is by the failure to extract rainfall from weak disturbances through the effects of reduced convection. Still, it should be stressed that the magnitude of the thermal differences of the surface are such, that weakening the local, thermally driven circulation can be postulated. In discussing semi-quantitatively such a postulate, the work by Estoque (1961) can be cited. Estoque constructed a nonlinear model of the sea-breeze, with vertical turbulent fluxes of heat and momentum, decreasing and disappearing at the 2 km altitude. The sea temperatures remain constant throughout the 24 hours, but at land the temperatures are prescribed by a harmonic wave with an amplitude of $\pm 10^{\circ}$C. Estoque obtains a sea-breeze with speeds up to 10 m/sec at 250 m, starting at a coastline and expanding towards both sides. Inland a convergence zone develops with vertical components of 0.15 m/sec.

It will be recalled the measured temperature difference was 4°-5°, and that one of the simulation results (Otterman et al., 1974b) was that temperature effects of 8°C-12°C can be expected when overgrazing occurs over wide areas at low and mid latitudes. These effects thus can be of the same order of magnitude as midday land-sea temperature difference of 10° introduced by Estoque into his simulation study. An enhancement of sea-breeze in the range of 40%-120% can thus be postulated.

POSSIBLE RAINFALL REDUCTION IN DENUDED AREAS

The process of climatic desertification by overgrazing by the surface tempera-
ture reduction remains at the present purely a hypothesis: no rainfall statistics
are presented as a direct evidence of rainfall reduction as a function of either
time or space change of land characteristics due to overgrazing. An analysis
of rainfall in Beersheva was carried out to assess a possible dependence on the
thermal mountain of the Western Negev, by comparing the rainfall average up
to and including 1947/48 rainy season with the average for the period 1948/49
to 1972/73, to test for the possibility that a significant change occurred in
1948/49 with the creating of an armistice line boundary around the Western
Negev. No statistically significant change was detected. Beersheva's position
is considerably inland, in the Central Negev, and it was selected only as the
nearest location for which longer term rain statistics are available.

There is a pronounced rainfall gradient from the Negev to the Sinai, the yearly
average decreasing from 600 mm in the coastal plains of central Israel to about
100 mm in the Sinai. However, this difference is attributable to other effects,
since geographically the coasts of central Israel benefit from a western exposure
to the Mediterranean, at a more northern latitude.

In spite of this difficulty, a program of rainfall measurements is proposed to
delineate the spatial rainfall dependence in the neighborhood of the Sinai/Negev

demarcation line, for which 9 AM-9 PM measurements will be available separately from the 9 PM-9 AM measurements. The importance of this temporal distinction lies in an expected correlation of the showers with the high land temperatures, especially in October-November and March-April.

Thus, in this section, observations are discussed which can serve only as indirect arguments in support of the outlined hypothesis. Direct evidence would have been concise; indirect has to be lengthy.

The hypothesized effectiveness of the mechanism, just as the effect of mountains on precipitation, is limited to the thermal mountain extracting (areas with reduced surface temperature, non-extracting) rainfall from weak disturbances or by inducing instability into undisturbed atmospheric conditions under right conditions such as discussed by Parry (1956) for his urban storm. Observations by Riehl (1949) show that in large disturbances precipitation would tend to be general over both low and mountainous regions; it is logically extrapolated that the precipitation in such cases must be general and essentially uniform over thermal mountains and cooler terrain. With clouds extending over wide areas, the thermal mountain/cooler terrain contrast, which hinges on the solar illumination, would not be built up in the first place. Thus, complete agreement exists to the point made by Charney et al. (1975), that this local process, to which they refer as the Otterman mechanism, cannot directly affect the large-scale monsoon precipitation in the Sahel or large-scale monsoons elsewhere.

We turn our attention to the lands in the vicinity of the Sinai and the Negev, with the Mediterranean type of climate, the region of the Egyptian, Judaic, Greek, Roman and Moslem civilizations. Warm, wet winters and hot, dry summers make it perhaps the most desirable of yearly climatic patterns. The zone is delineated (Griffiths, 1972) by the sea as its northern edge and by the 125 mm annual isohyet to the south (Griffiths, 1972). Few parts of the zone are more than 300 km from the coast while in Libya and the United Arab Republic the band is about 30 km wide. In our considerations, we would like to include Sardinia, in the West and the Sinai with the Judean plain of Southern Israel in the East.

In this region of Mediterranean coastline of North Africa, Black and Tarmy (1963) analyzed the influence of the mountains on the rainfall, and point out that here mountains only 3000 feet (1000 m) high average 20 to 30 inches (500 mm to 750 mm) of annual precipitation in contrast to only 3 inches (75 mm) on the near-by flat coastal plain.* They argue, that since Stern and Malkus (1953) established the functional equivalence for inducing convection by a heat island vs. an actual mountain, an asphalt heat island with appropriate dimensions can induce a comparable rainfall. They envisage a temperature advantage for the asphalt of 9°F (5°C), approximately the same as the temperature difference we established for the protected vs. the overgrazed area at the Sinai/Negev boundary. We repeat

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*Turnage and Mallery (1941) fit straight-line equations to rainfall observations in the Sonoran desert, and obtain for the summer rainfall a dependence that ranges from 100 to 200 mm for a 1000 m elevation.

Black and Tarmy's argument, and suggest that overgrazing can produce a serious reduction of rainfall.

Specifically, the effect might be regionally more significant in October-November and February-March periods, rather than during the main seasonal rainfall of December-January.

Consider the rainfall and wind table the rainy half year, for Sirte, Libya, Table 3 (reproduced from Griffiths, 1972, Table XV, p. 55).

Table 3

Rainfall and Wind Table for Sirte, Libya

Elevation 20 m, Latitude 31° 12' N, Longitude 16° 35' E

	Precipitation				Wind			
	Mean (mm)	Max. (mm)	Min. (mm)	Max. in 24h	Av. Speed (knots) 07h 13h		Prevalent Direction 07h 13h	
October	16	67	0	67	6	7	S	N
November	33	122	0	43	7	7	S	NW
December	38	101	0	37	7	8	SW	W
January	40	95	2	11	8	9	SW	W
February	23	65	0	19	8	8	S	NW
March	16	79	0	24	7	8	S	NW
Annual	187	349	66	67	7	7	–	–

It is stated by Griffiths (1972, p. 45) that the coastal areas receive maximum rainfall during December or January, while the inland regions tend to show double maxima, straddling the temporal maximum for the coastal region.

From the data in Table 3, it can be observed that October-November and March rainfall is pronouncedly more variable, in terms of monthly maximum to monthly average ratio, and especially maximum in 24h to monthly average ratio, than the December-January rainfall. This is strongly suggestive that the October-November and March rainfall is predominantly of the unstable type as compared to the stable December-January rainfall.

The distinction between these two types of rainfall was stressed by Trewartha (1961, p. 235), who stated that insight into the origin of the rainfall is gained by separating the rainfall-frequency data according to whether the precipitation is of the unstable type, showers and thunderstorms, or of the stable type, gentle and long continued. The stable type is quite uniform over larger areas.

Based on the seasonal coincidence it is the unstable rain that appears to be more penetrating inland. And it is for this type of unstable rain that the reduced surface temperatures-reduced convection effect can be postulated for these three reasons:

(a)   the basically local convection triggering mechanism is not likely to affect the stable rain, falling anyway over a wide area, as discussed before

(b)   rain from clouds over wide area would shadow these areas, eliminating

essentially ground temperature differences*

(c)   The solar insolation is stronger in October-November and in March

than in December-January. The soils, on the average more dry than in

December-January, would exhibit higher temperature differences.

The work of Sharon (1972) is thought to be highly pertinent to the whole problem

area. Sharon studied the rainfall in the Southern Arava, southernmost, extremely

arid part of Israel. He found that between one-half and two-thirds of the total

rainfall is of a highly localized type, coming mostly from small convective cells.

In a number of storms, the dimensions of such cells could be estimated; the

typical diameter was about 5 km. Correlation analysis has been used to study

the degree of spottiness. In the beginning and end of the rainy season correlation

is extremely low, indicating high spottiness, whereas spatially uniform rainfall

is most likely to occur in mid winter.

Sharon reports in more recent studies a high degree of rain spottiness in the

Negev (Sharon, 1975), where more than half of the rainfall is quite localized in

the early and late rains, and also a large fraction of the main-season rains.

Regionally for the Mediterranean coasts no more than 50% of all rainfall is of

convective origin (Flohn, 1975).

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*Ground temperature differences can certainly exist under the conditions described by Turnage
and Mallery (1941, p. 6) in the Sonoran desert, where heavy showers often fall in midafternoon
from a sky which was cloudless at dawn.

Precipitation linked to a thermally driven local circulation has been extensively studied by Flohn (1965; 1969). His conclusions are: "the divergences and convergences between different diurnal circulations and with the large-scale prevailing flow are, to a large extent, responsible for regional patterns of precipitations and cloudiness, especially in low latitudes. In middle and high latitudes the role of radiation is rarely as significant as in the tropics and in arid areas." This work is here referred to as establishing the important effect of local, thermally driven winds in producing precipitation in arid areas, to which we are anyway constrained by the invoked growth of the vegetation in clumps.

In connection with this last point it should be noted, Table 3, that in December-January the 07h wind is SW, and the 13h wind W, indicating the prevalence of the Westerlies and their presumed predominant influence of the rainfall. However, in October-November and February-March, the 07h wind is S in each case, and the 13h wind NW in three months and N one month. This indicates strongly a role for sea-breeze as interacting with the Westerlies.

Black and Tarmy discuss orienting the asphalt coating with its long axis parallel to the prevailing daytime winds, to obtain the benefit of inducing or strengthening the sea-breeze circulation. Citing Estoque (1961) on one hand and Flohn (1969) as quoted above, on the other, such an inducement of the sea-breeze can be considered a highly important factor for advocating that asphalting the coastal strips

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will produce rainfall, or for postulating that overgrazing along the Mediterranean coast has produced desertification not only by reducing convection, but also by reducing daytime advection.*

Based on Sharon's findings, and inferences from the Table 3, statistics for Sirte, a reduction in the spotty rainfall, through overgrazing, can sharply reduce the total rainfall in arid and semi-arid regions. This would apply apparently to most of the Mediterranean lands.

No direct evidence for such processes can be now brought forward. Rosenan (1963) reports a very interesting phenomenon, that precipitation amount of Tel-Aviv, calculated as a ratio to the precipitation of Jerusalem Haifa and Beirut, shows a systematic and statistically significant increase of 20% from the decades early in this century to the mid-century. Rosenan actually discusses the possibility that agricultural practices and cultivation of relatively tall vege-tation induced this effect, but indicated that quantitative explanation has not been developed. Today, the most likely explanation appears to be the urban heat island effect. From the nineteen-twenties, Tel-Aviv developed much faster than the other three cities.

On a longer time scale, Butzer and Twidale (1966) analyze a reduction in rain-fall in the Mediterranean lands from the late prehistoric (5500-2350 BC) to modern times. In the region from the Negev to Tunisia they indicate on the

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*For an analysis of the afternoon excess of precipitation in the USA, see Wallace (1975).

basis of archaeologically recorded zoological evidence large shifts to the North of 50, 100, and 150 mm isohyets. The present day 50 mm isohyets approximately coincide with the 150 mm isohyets of the late prehistoric (Butzer and Twidale), 1966, Fig. VII-4). It is postulated here that a large part of this effect can be attributed to the overgrazing in the region during the last few millenia. More detailed study, what fraction of the rainfall in the region is of the spotty characteristics is undertaken (Sharon, 1975). The effect should become stronger when measured as a fraction of the total local rainfall, for the inland areas. Notwithstanding the increase by the mountains by a factor of 7 to 10 reported by Black and Tarmy (1963), and pending further study, a reduction in rainfall by a factor of three seems high to be attributed solely to the mechanisms described here. It is quite likely that there was also a shift of the great rainfall belts during the course of historical fluctuations in the last 5000 years (Flohn, 1975).

The Mediterranean lands were rather densely populated in some parts even in the late prehistoric and in the historic periods, and early anthropogenic pressures in those parts can be expected. Other areas witnessed only a recent population explosion, by an order of magnitude during the last two centuries. The special impact of the modern medicine is especially evident in the population growth rates in developing nations only in the last few decades.

Thus, globally strong anthopogenic influences are a recent phenomenon. However, overgrazing is attributable not only to domesticated animals but also to wild animals, and impact on the Earth surface at any past period cannot be excluded.

Overgrazing effects have been observed on the ERTS (now LANDSAT) imagery of many regions. A quite long demarcation line exists longitude 20°E, along the border of bright, overgrazed Botswana and darker vegetated South West Africa. The Afghanistan-USSR international boundary shows in a sharp contrast uniformly bright areas of Afghanistan, overgrazed by sheep vs. darker area of South eastern Kara Kum in the Soviet Union. The contrast is essentially identical to an inland pair of points, pair #3 across the Sinai/Negev demarcation line (Otterman et al., 1975b). An ERTS image of Central-Northern Australia, E-1210-00310 of 18 February, 1973, shows effects of overgrazing north of Barrow Creek. An exclosure is darker in all the bands of the Multi-Spectral Scanner.

It appears that many other areas apart from the Mediterranean lands could have been affected by the surface temperature reduction — reduced convection mechanism. Two regions of inherently very bright soils of arid coastal regions, within 300 km of ocean, are thought to be especially likely to show such effects: and regions of the west coast of South Africa, in Namib Desert Region, and the arid areas of coastal regions of Australia.

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SUMMARY AND CONCLUSIONS

Overgrazi g by denuding the soil from its vegetative cover can affect strongly the nature of the Earth surface, increasing the albedo of inherently bright soils by a factor of up to two. The vegetation of arid regions affect the reflectivity directly, and also indirectly, by producing debris and by stabilizing the soil, reducing the dust that would cover the debris. On the other hand, trampling by the grazing herds tends to bury the debris in the overgrazed areas.

The higher albedo of the overgrazed regions tends to reduce the surface temperatures when compared to the vegetated regions under sun-illuminated conditions. Recent calculations indicate that the albedo of Sinai approaches 0.50. With such a high albedo, and an albedo ratio of 2.0, the ratio of visible and reflective infrared absorptivities of the surface between the overgrazed area and vegetated area is about 2/3. Based on calculation and fragmentary observations, the temperature differences can be of the order of 4° -12°C.

The impact on the global energy balance of overgrazing can be significant. It has been calculated that overgrazing in the Sahel, assuming no climatic feedback, can produce radiation balance effects comparable to those due to the shifts in the ice cover (Otterman, 1974). This calculation was carried out assuming an albedo difference of 0.12 between overgrazed and protected areas. The values recently calculated indicate that the difference can be twice as much, by 0.22 to 0.24.

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Regional climatogenic effect of desertification by rainfall reduction can be substantial. It appears that a quite strong effect can be expected in reducing localized, spotty precipitation. Such precipitation forms a large fraction of the total rainfall in arid and semi-arid regions. Specifically, the thesis is advanced, that the desertification in the Mediterranean lands that apparently occurred from the late prehistoric times is principally due to overgrazing, through the reduced surface temperatures — reduced convection mechanism. Other areas, especially the Namib arid region and Australia coastal areas could have been similarly affected. Essentially, a negative of thermal urban island, as discussed by Landsberg (1974) prevailing over large arid and semi-arid areas is suggested.

This multi-facet study should in no way be regarded as definitive, neither for the whole problem area, nor for any of the sub-topics. On the contrary, in spite of the efforts since the winter of 1972/73 to study and analyze these phenomena in which the author's colleagues and students ably and effectively participated, uncertainties and questions exist in each of the sub-topics. Continued studies by many workers are warranted because of the hypothesized significant effects on our environment.

ACKNOWLEDGMENTS

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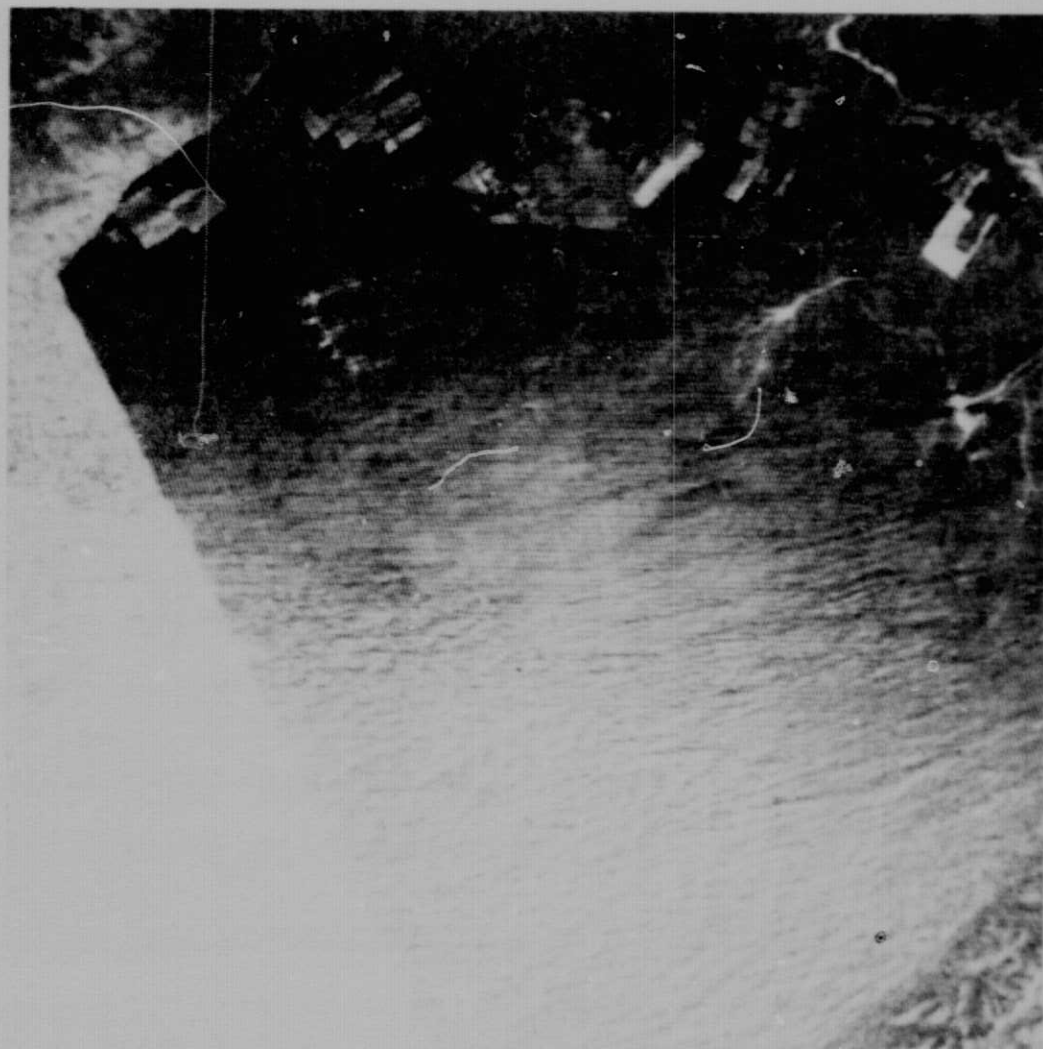Metheun, and UNESCO, 31-52.

Figure 1. Coastal area of Israel, the Western Negev and the Northern Sinai, ERTS image E-1091-07482, taken on 22 October 1972, photographed from General Electric Image 100 Analyzer.

Figure 2. Ground view of the Negev showing vege-
tation growing in clumps. Tamarisk trees as shown
in this figure occur only occasionally, as individual
specimens.

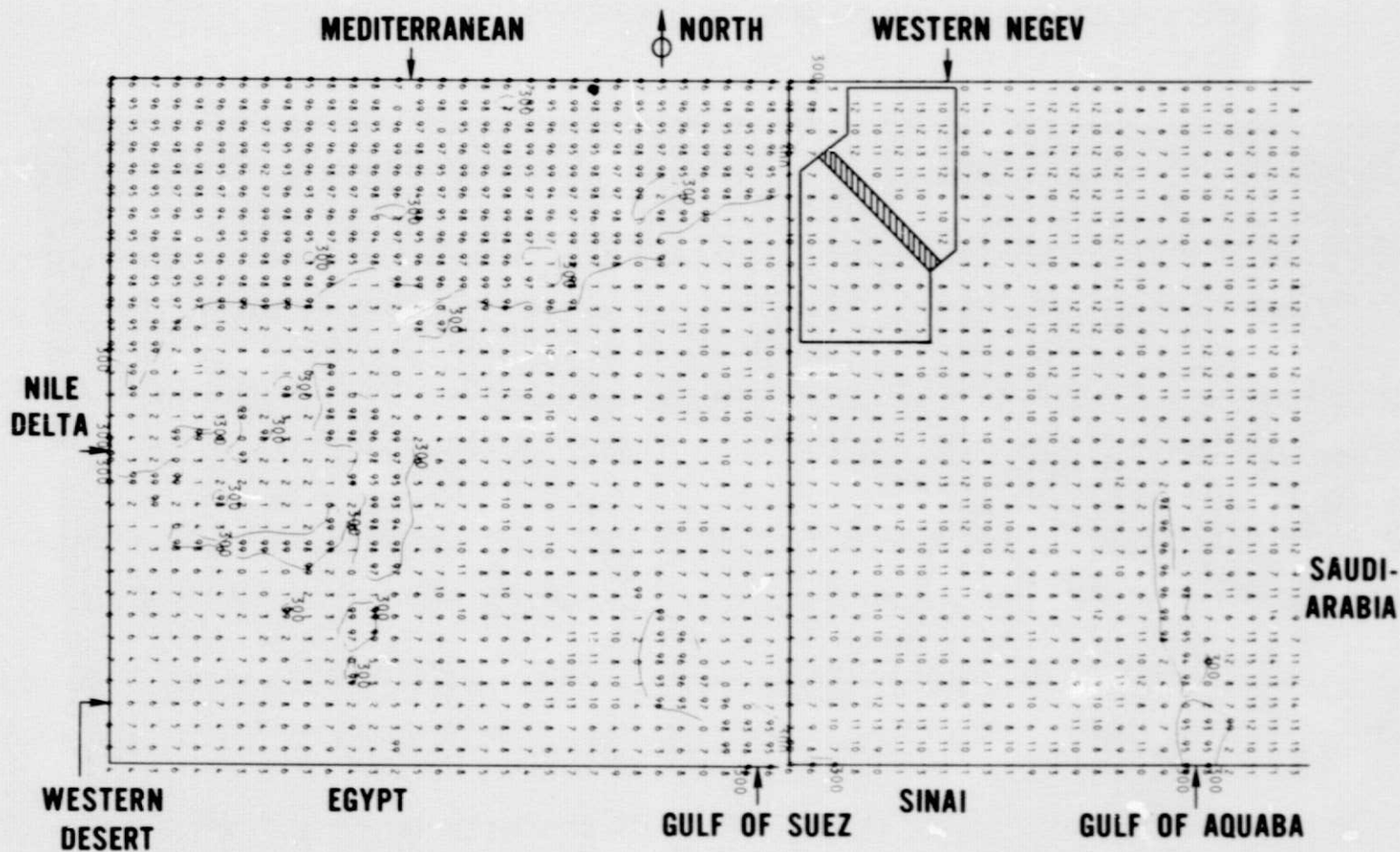Figure 3. Watermelon cultivation in the
Northern Sinai.

Figure 4. Radiation temperatures map of the region taken by the SR (Scanning Radiometer) of the NOAA-3 satellite, July 15, 1974.

Figure 5. Convection cumulus forming over the coast, the Gulf of Guinea ERTS (LANDSAT)
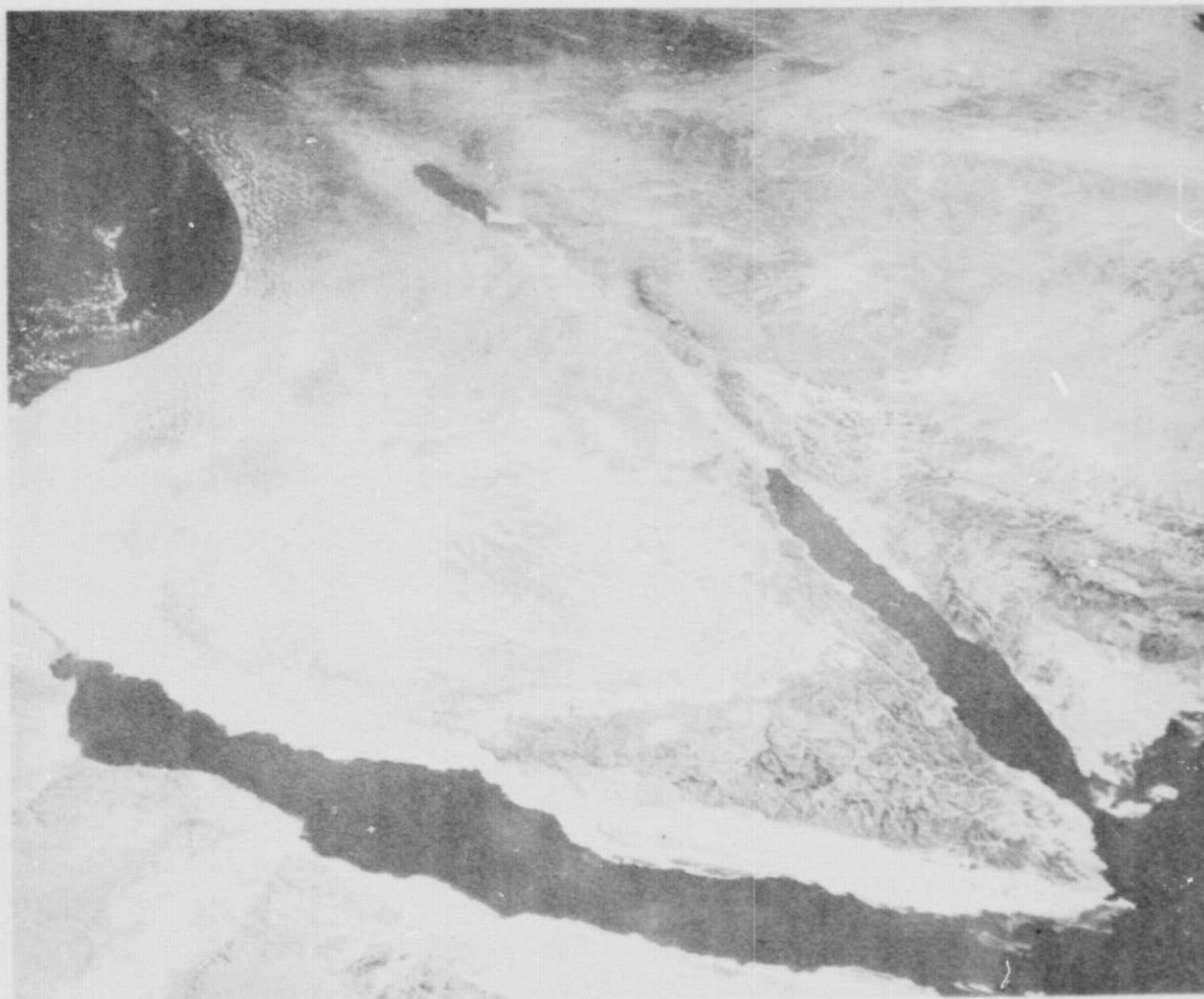Image E-1159 09165, 29 December 1972.

Figure 6. Gemini XI image of the Sinai and the Negev, showing clouds over the Negev, September 11, 1966.